Improved photon shot noise effect on LWR by using attenuated PSM for EUVL

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Agenda

- What is photon shot noise?
- Attenuated PSM
- Stochastic simulation condition
- Simulation result
- Conclusion

What is photon shot noise?

Attenuated PSM

Stochastic simulation condition

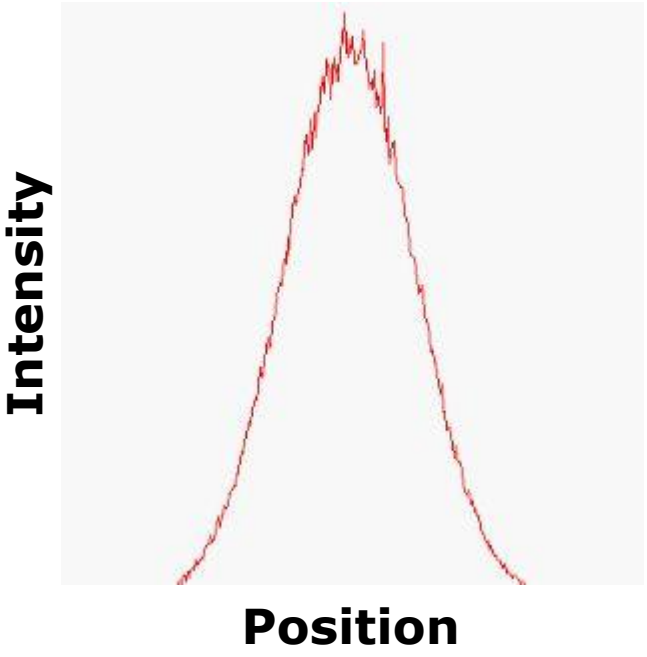
Simulation result

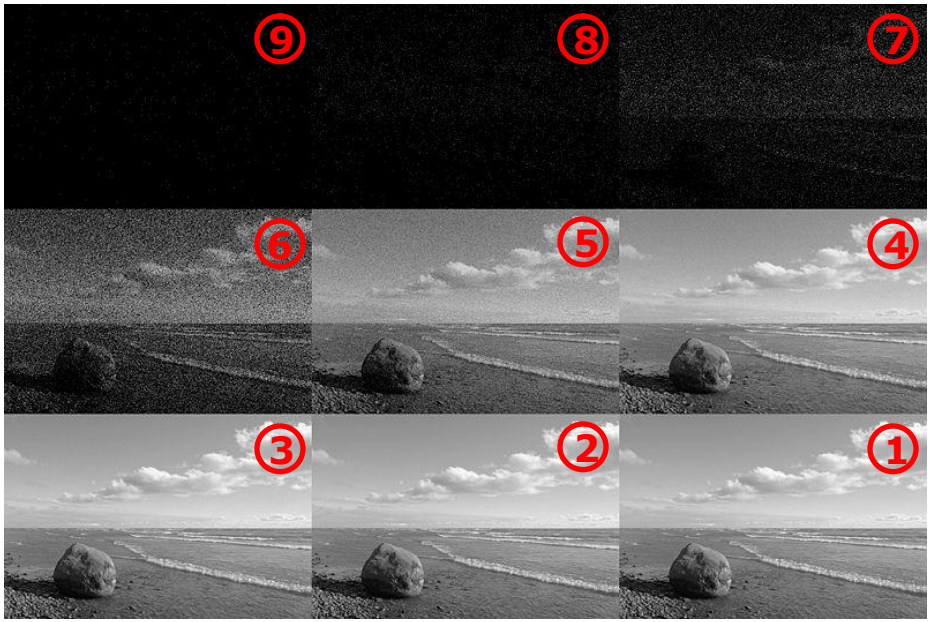
Conclusion

What is Photon Shot Noise?

Fluctuations of the number of photons detected due to their occurrence independent of each other.

The term "shot noise" → analogy of the discrete photons that make up a stream of light to the tiny pellets that compose the stream of buckshot fired from a shotgun.





magnitude of shot noise increases

PSN Effect in Photo-Lithography

Statistical fluctuations between photon and photo resist (PR)

Exposure dose → number of quanta

Photon energy and dose

Smaller number of quanta for shorter wavelength → Large photon shot noise

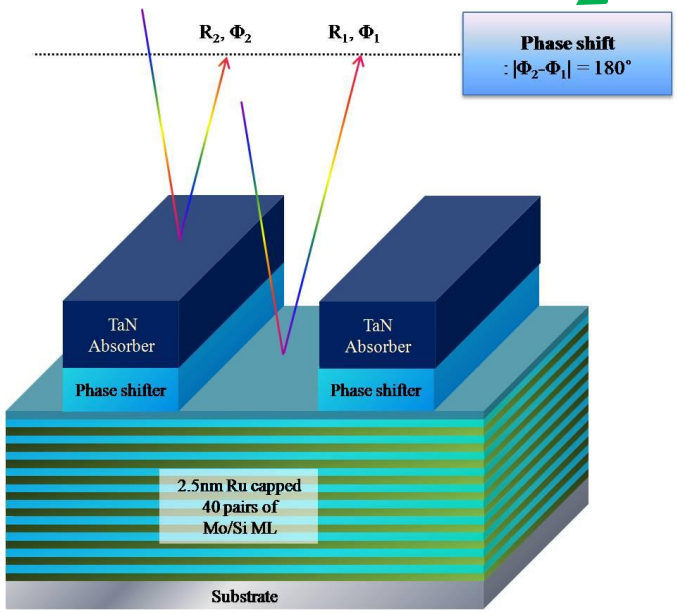
$$E = h\nu = \frac{hc}{\lambda} \rightarrow \text{Dose} = N_{photon}E = N_{Photon}\frac{hc}{\lambda}$$

Lithography	Energy (eV)	Wavelength
ArF	6.4	193nm
EUV	92	13.5nm
E beam	50,000	5.5pm

Ref. : JVST B Vol. 21 , 2632 (2003)
SPIE Vol. 7520, 752004 (2009)

Shot Noise Effect for LER & LWR

$$\text{LER \& LWR} \propto \frac{1}{\sqrt{\text{dose}}} \propto \frac{1}{\sqrt{N}}$$



total absorbed photons
or
1st order diffracted photons??

The number of absorbed photons(number of quanta) / generated acids in exposed area is the key factor for mitigating PSN effect.

Ref. : SPIE Vol. 5374, 79 (2004)

What is photon shot noise?

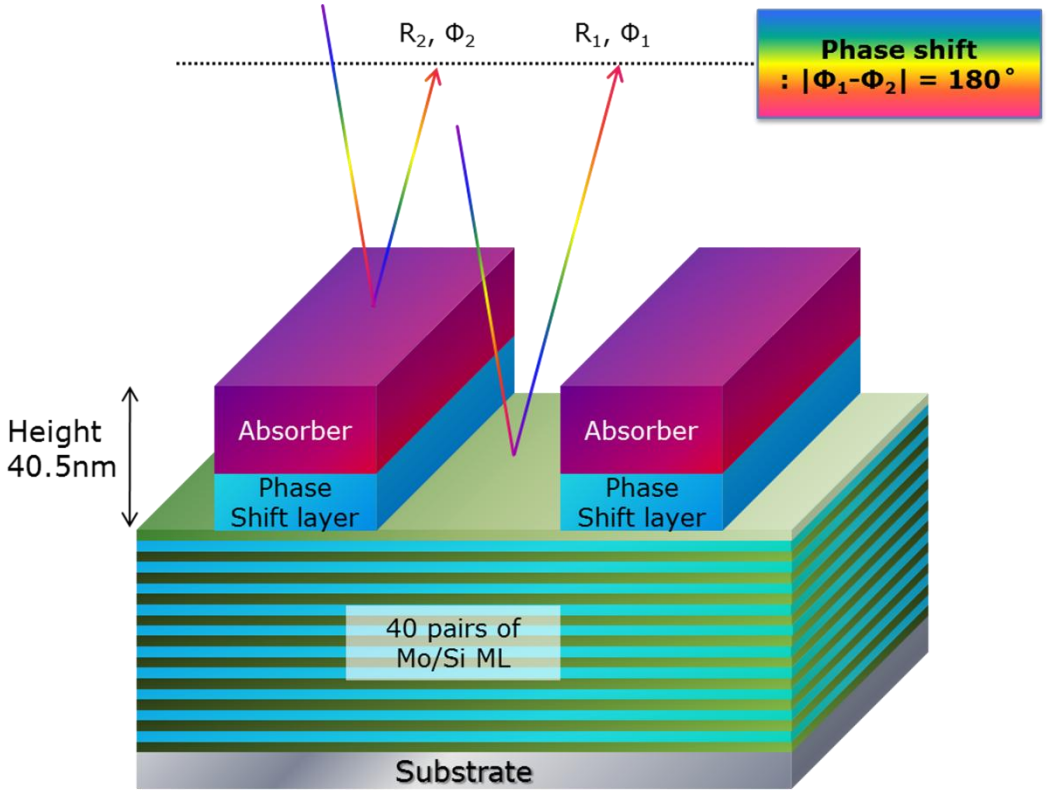
Attenuated PSM

Stochastic simulation condition

Simulation result

Conclusion

Attenuated PSM



Schematic image of attenuated PSM

Phase shift ($\Delta\Phi$) = $(2\pi\delta/\lambda)^*\Delta r$

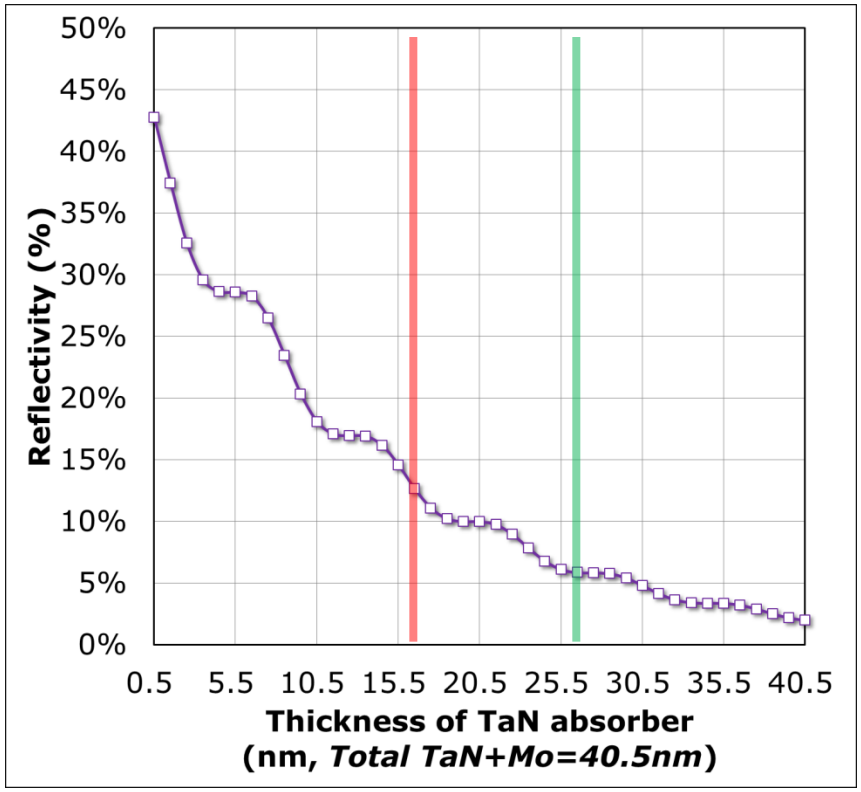
(Δr = propagation distance)

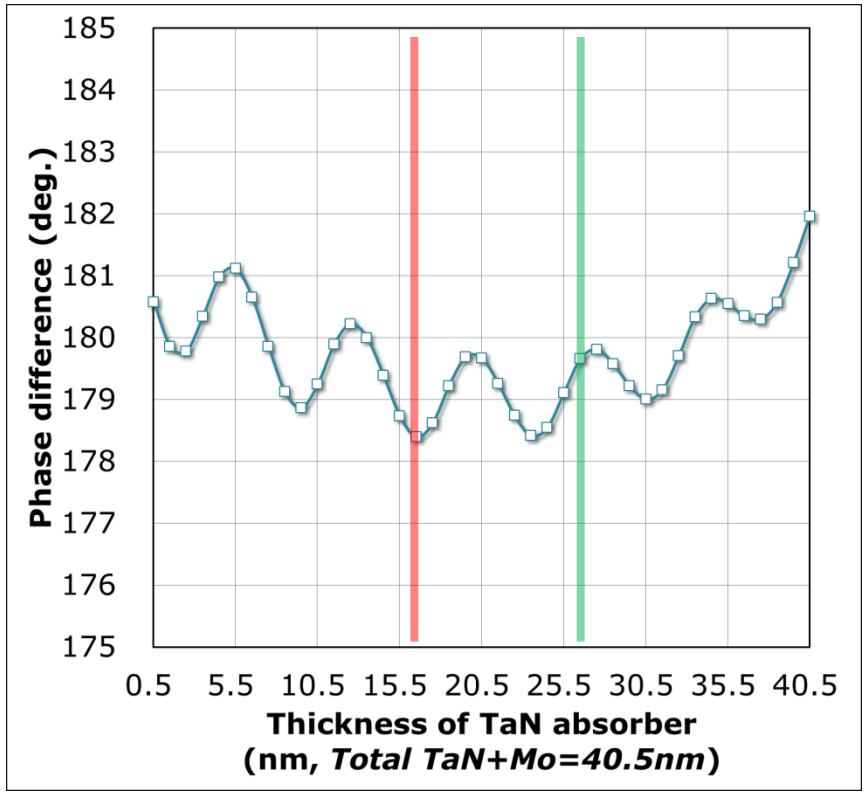
Material	n	k
TaN	0.9260	0.0436
Si	0.9991	0.0013
Mo	0.9238	0.0064
Ru	0.8864	0.0171

Refractive index (n)= $1-\delta + i\beta$

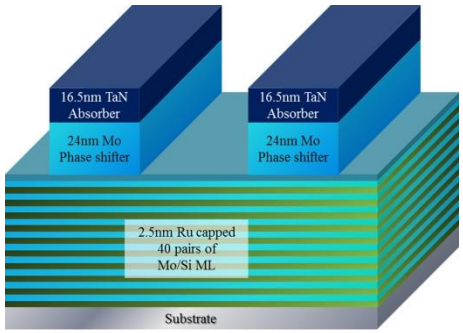
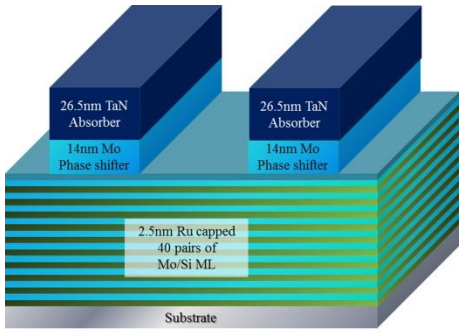
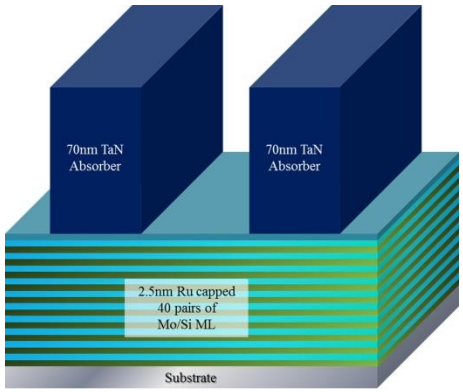
Ref. : JVST B Vol. 31(2) , 021606 (2013)

Attenuated PSM (cont.)





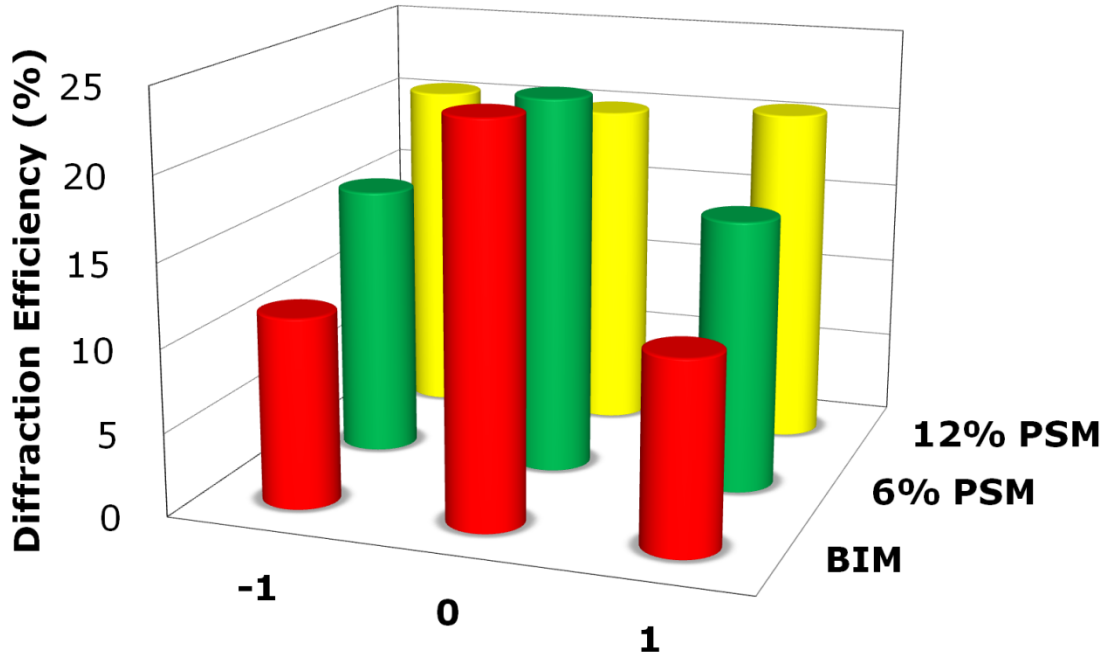
Mask Stack

	12% PSM	6% PSM	BIM
Mask			
Absorber stack	16.5nm TaN / 24nm Mo	26.5nm TaN / 14nm Mo	70nm TaN
Reflectivity	12.66%	5.85%	0.18%
Phase difference	178°	180°	79°

Ref. : SPIE Vol. 8679, 79 (2013)

Mask Characteristics

Diffraction Efficiency



	-1	0	1
BIM	11.45	23.72	11.45
6% PSM	16.37	22.83	16.37
12% PSM	20.55	20.01	20.55

What is photon shot noise?

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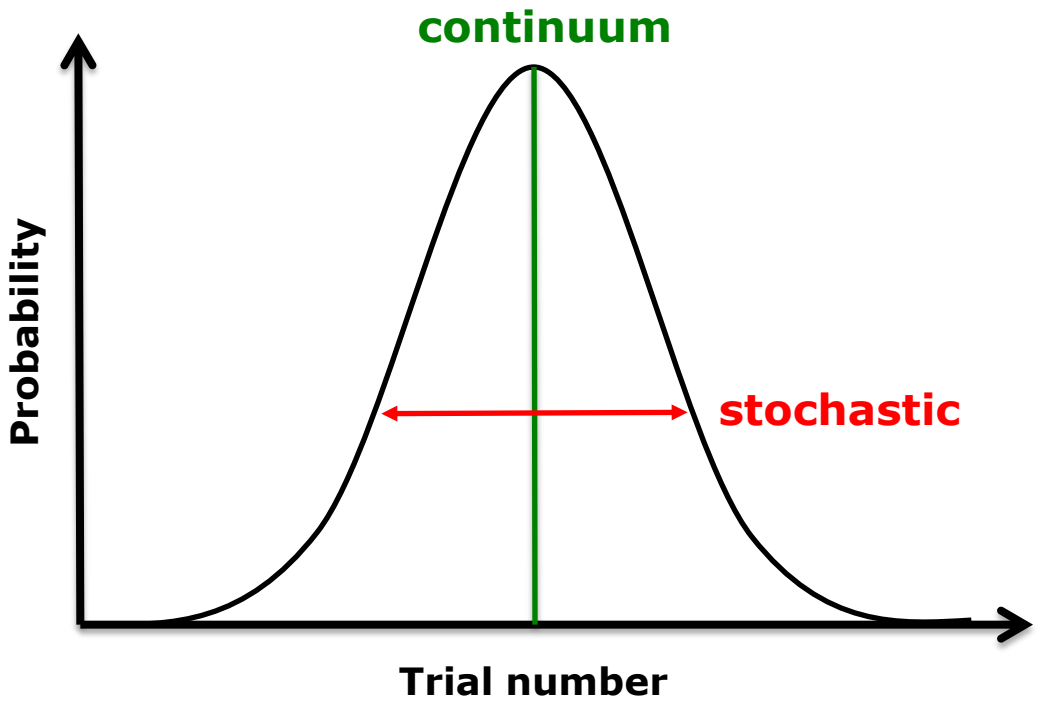
Stochastic Simulation

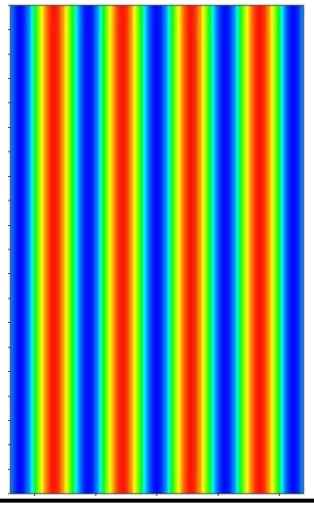
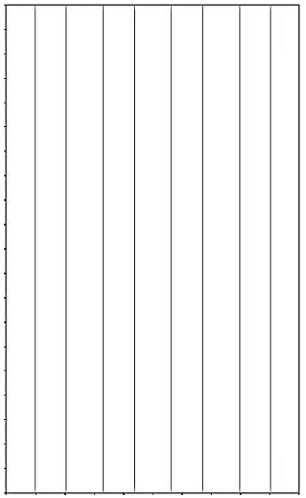
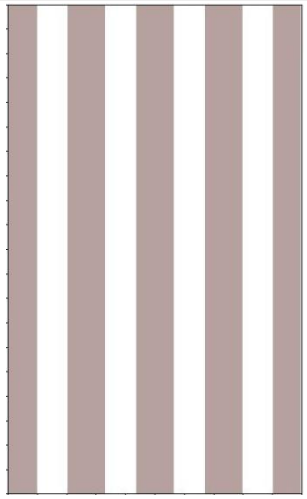
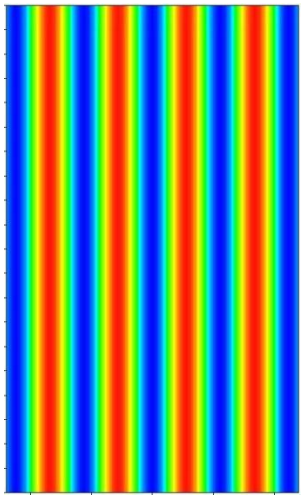
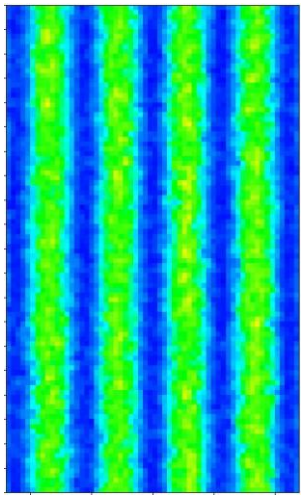
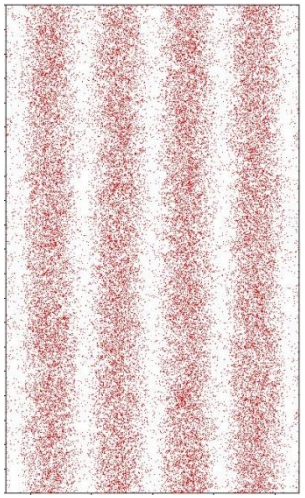
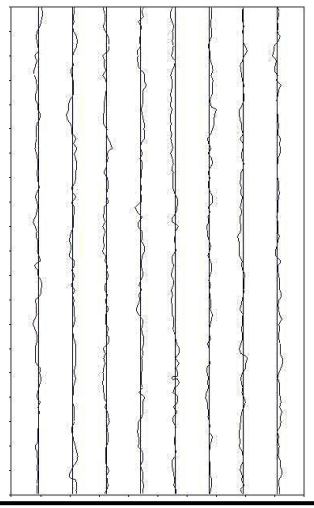
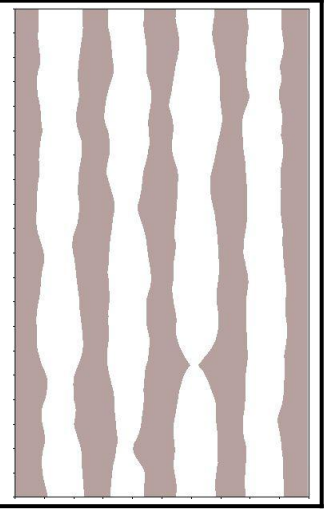
Continuum simulation (Analytical method) → One-condition

Stochastic simulation (Numerical method) → Non-deterministic

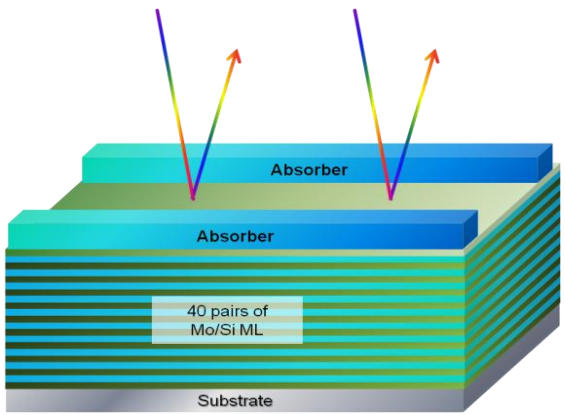
Gaussian distribution



Continuum vs. Stochastic

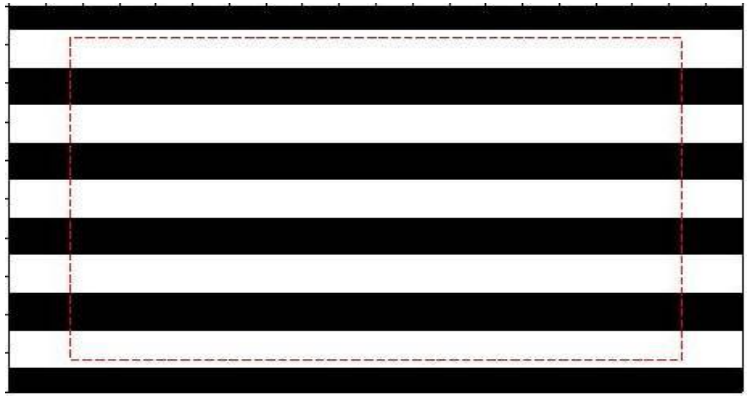
	Aerial image	Absorbed photons	Generated Acids	Latent image	Developed PR
Continuum		N/A	N/A		
Stochastic					

Simulation Condition

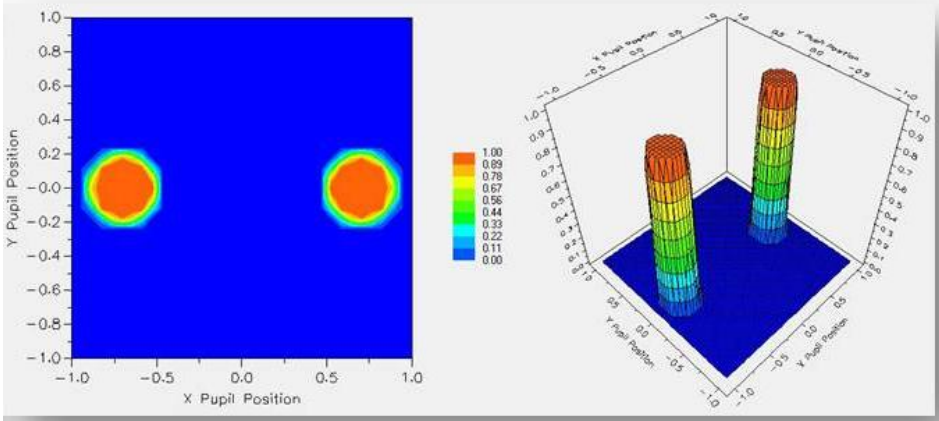


Parallel to EUV (non-shadowing)

Simulator	PROLITH X4 (KLA-Tencor)	
Pattern	14nm L/S half-pitch	
Resist	EUV generic resist model (Adv. CA) (offered by KLA-Tencor)	
Illumination	NA	0.33
	Shape	Dipole
	Wavelength	EUV (13.5nm)



14nm L/S half-pitch



Dipole (0.8, 0.2σ) illumination

What is photon shot noise?

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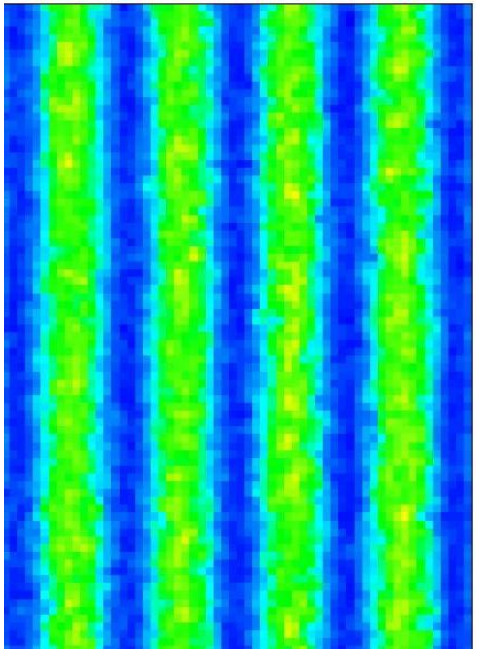
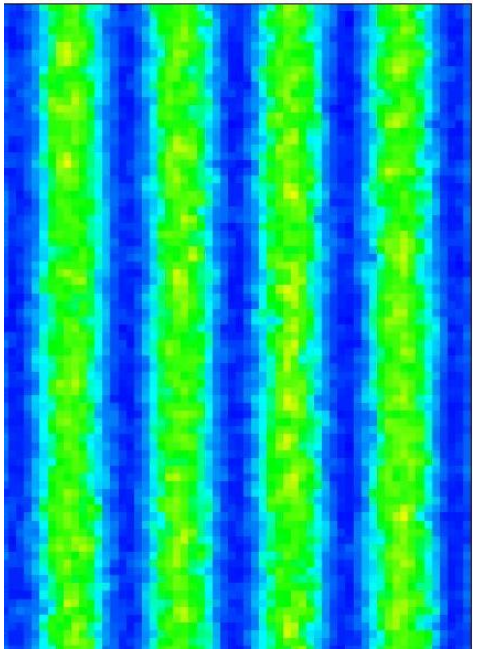
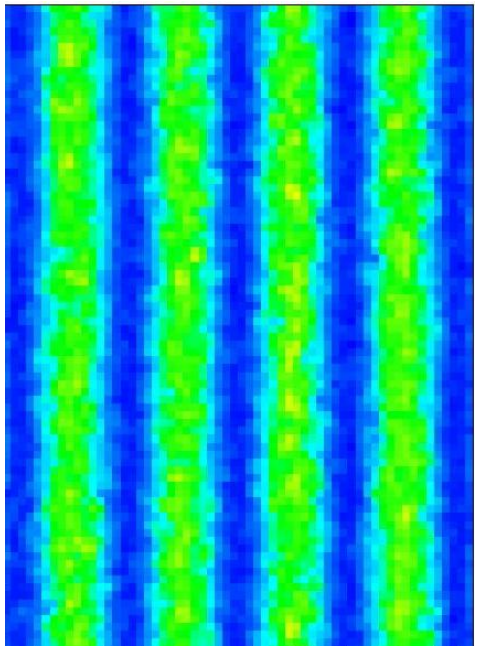
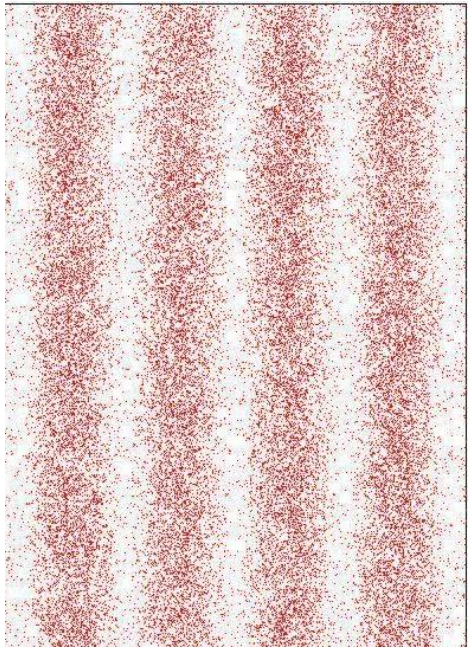
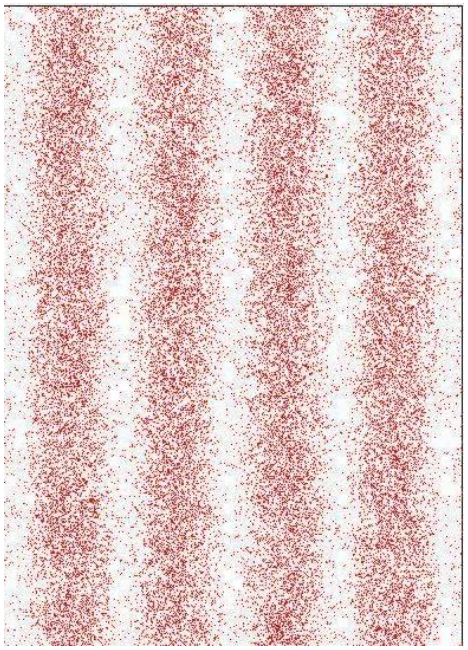
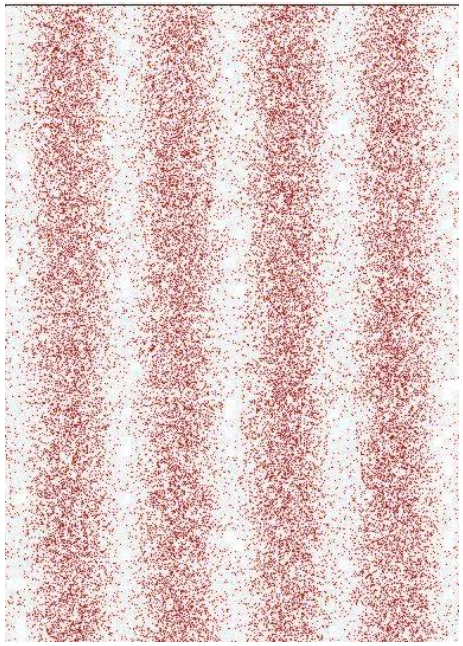
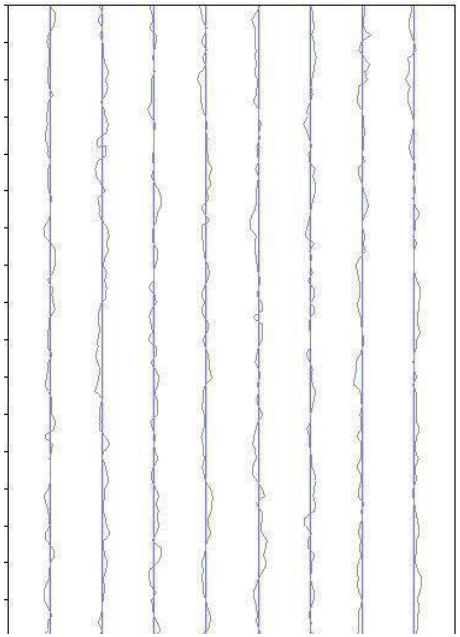
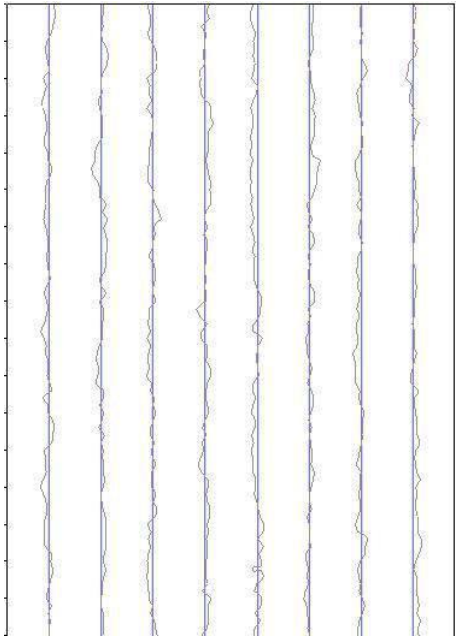
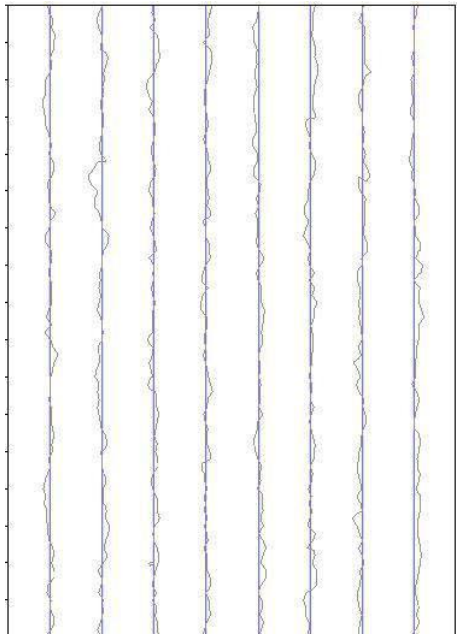
Absorbed Photons

Mask Stack	12% PSM	6% PSM	BIM
Dose to size (E_{op}, mJ/cm^2)	22.53	23.18	25.67
Focus	-69.5	-63.6	-53.5
Absorbed Photons			

Generated Acids

Mask Stack	12% PSM	6% PSM	BIM
Dose to size (E_{op}, mJ/cm^2)	22.53	23.18	25.67
Focus	-69.5	-63.6	-53.5
Generated Acids			

Latent Image after PEB

Mask Stack	12% PSM	6% PSM	BIM
Dose to size (E_{op}, mJ/cm^2)	22.53	23.18	25.67
Focus	-69.5	-63.6	-53.5
Latent image after PEB			

Developed PR

Mask Stack	12% PSM	6% PSM	BIM
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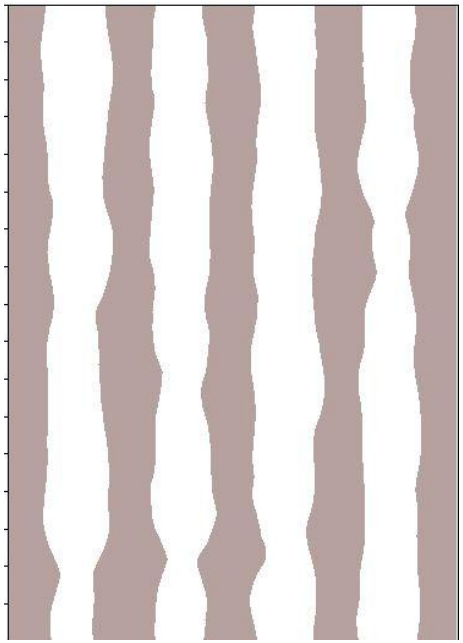
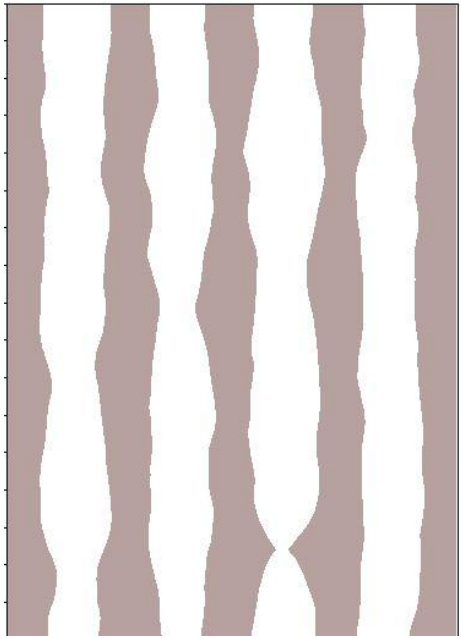
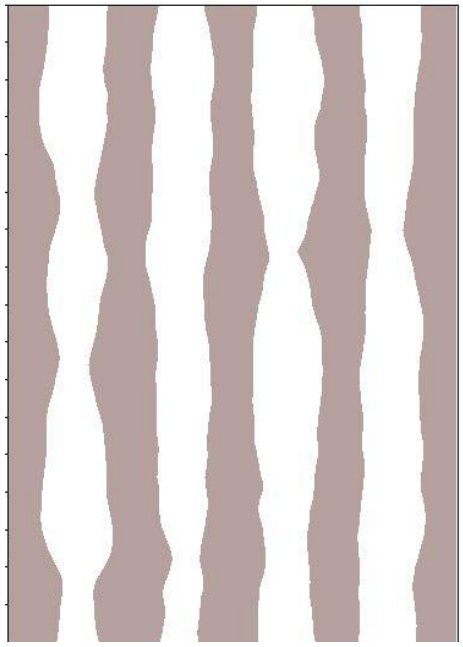
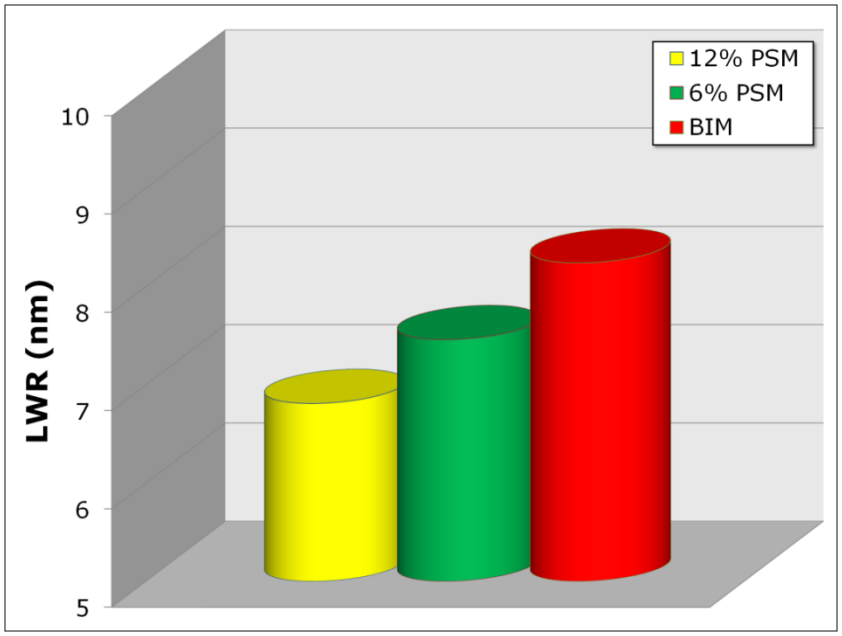
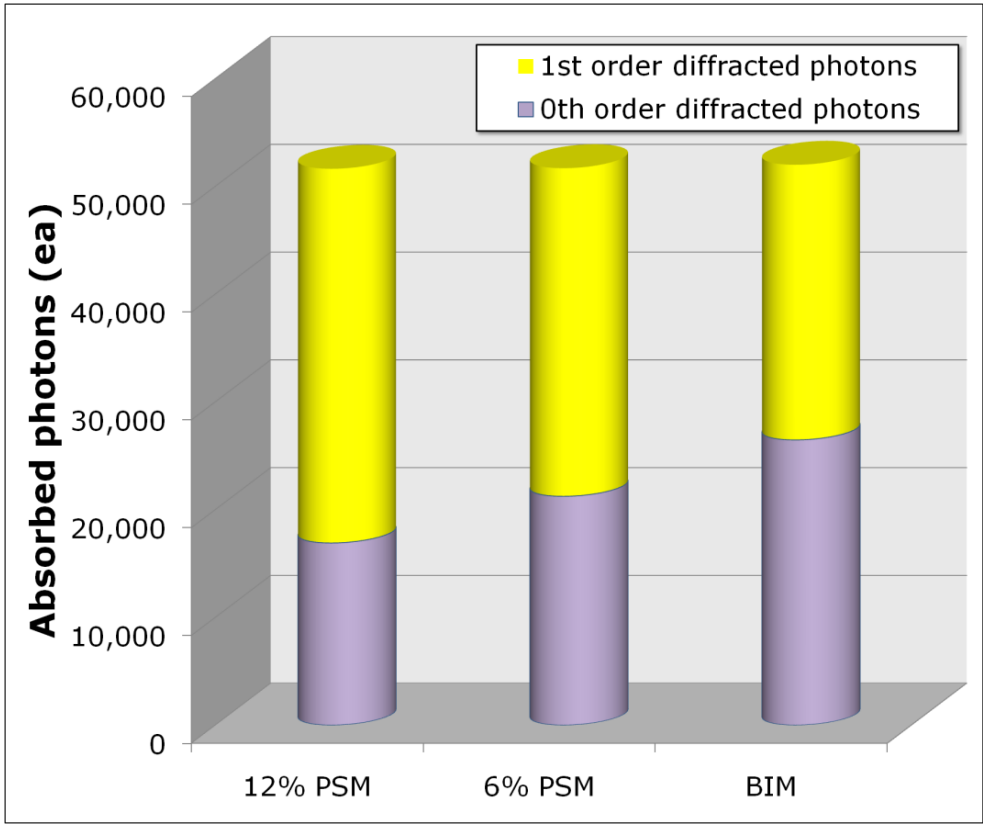
Focus	-69.5	-63.6	-53.5
Developed PR			

LWR & Absorbed Photons



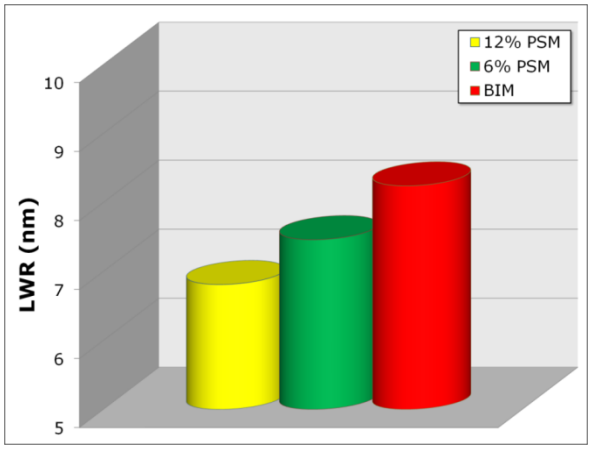
Total absorbed photons ≒ 51,500 ea



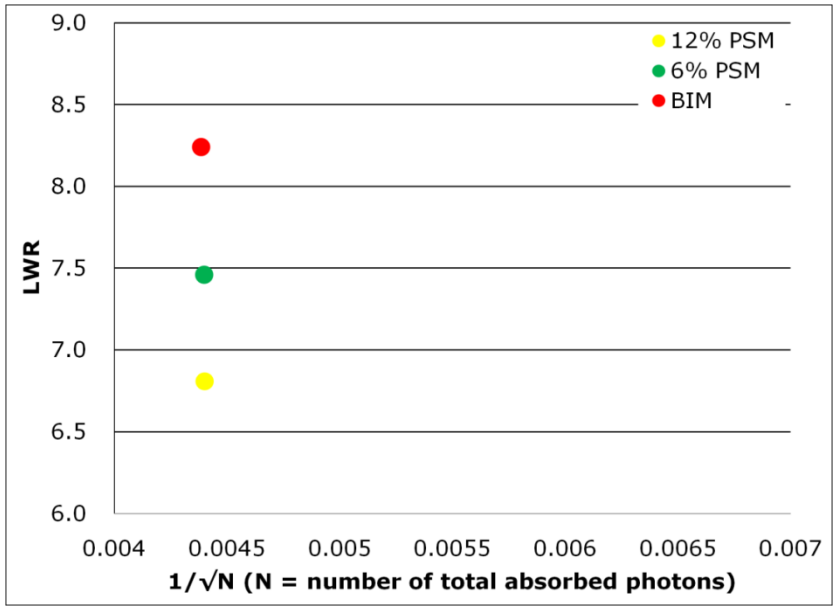
1st / 0th order diffraction ratio

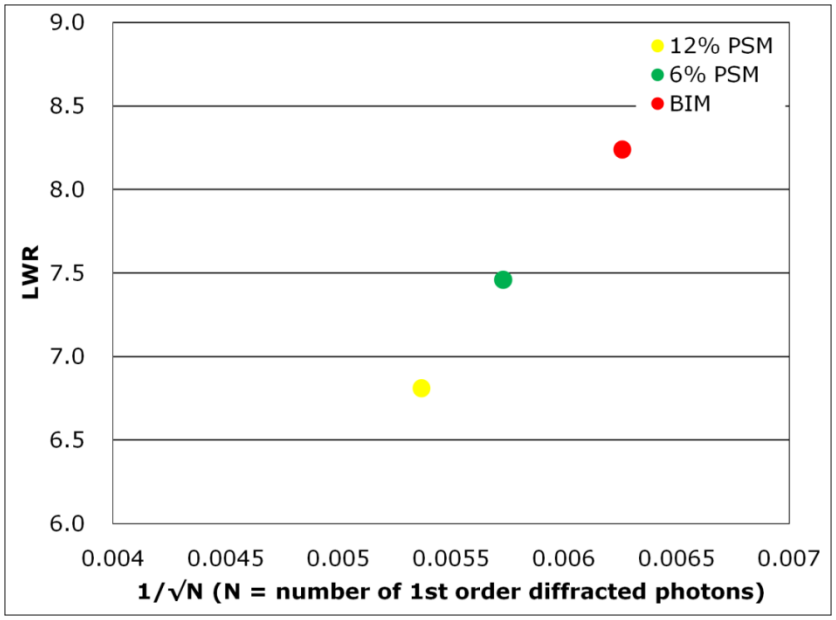
Mask Stack	12% PSM	6% PSM	BIM
1st / 0th order Diffraction ratio	2.05	1.43	0.97

LWR & 1/√N

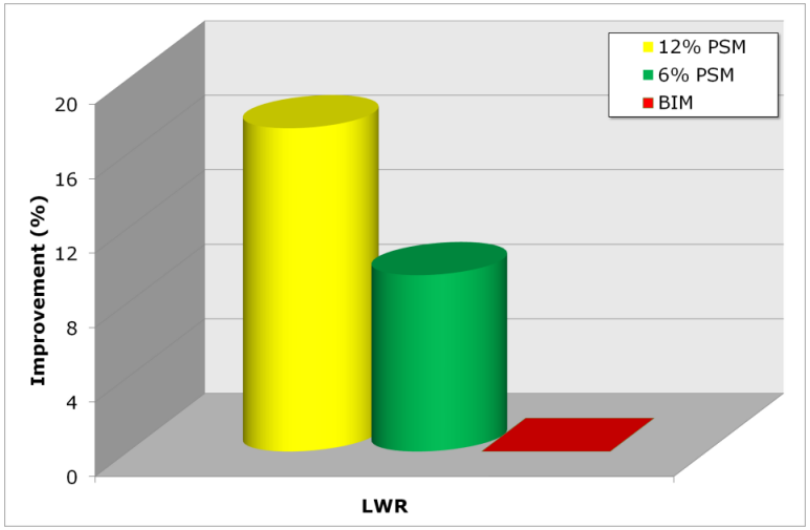


$$LWR \propto \frac{1}{\sqrt{N}}$$

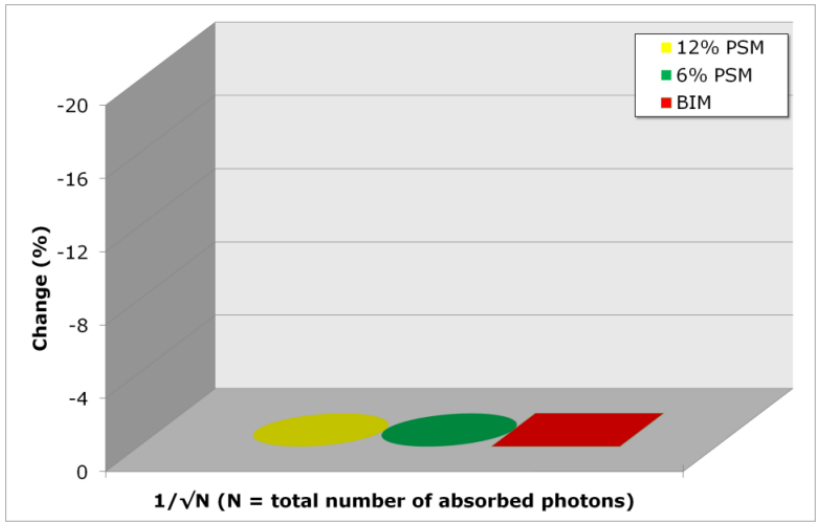


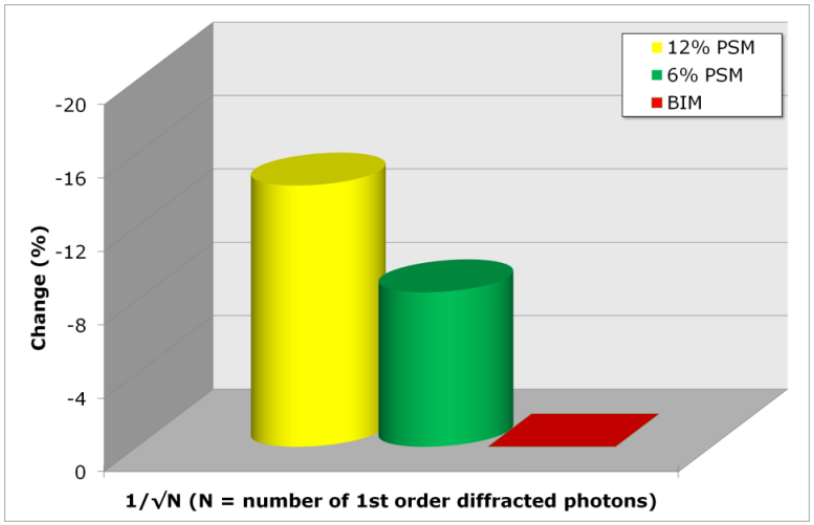


LWR & 1/√N (Cont.)



$$LWR \propto \frac{1}{\sqrt{N}}$$





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Attenuated PSM

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Conclusion

- Phase shift mask concept has been proposed to mitigate photon shot noise effect

- With proposed PSM, simulation results showed
  - Higher relative intensity vs. BIM
  - Transfer more 1st order diffracted photons onto wafer
  - Alleviate photon shot noise effect at even lower E_{op}
  - Improved LWR

$$\text{LER \& LWR} \propto \frac{1}{\sqrt{\text{dose}}} \propto \frac{1}{\sqrt{N}}$$

- Confirmed that 1st order diffracted photons are informative photons that affect photon shot noise effect

- Possibility of further works on PSM concept for even better performance!


Thank you for your attention.
Have a nice time in Maui!!!
Special thanks to KLA-Tencor for providing PROLITH